Jet Propulsion Laboratory
California Institute of Technology

Mars Reconnaissance Orbiter Operations: Science Planning on NASA's Silent Workhorse

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Caltech Planetary Science Seminar

April 4, 2017

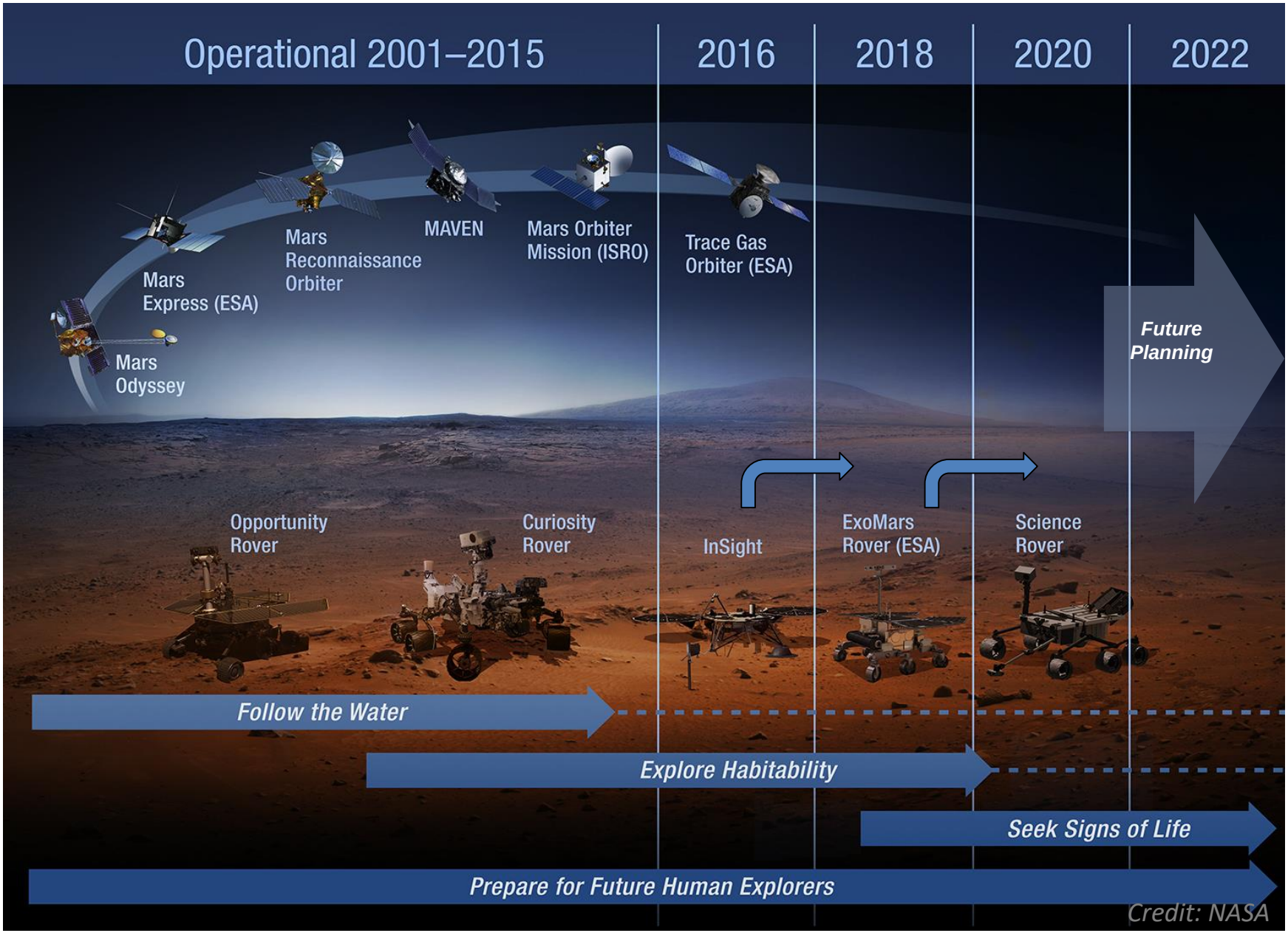
URS____


MRO
NASA + JPL
LM • UA • APL • ASI • MSSS

Outline

Science Planning on NASA's Silent Workhorse

- Overview of MRO
- Overview of Science Planning and Challenges
- Science Planning on MRO
- Landing Site Selection as example of Science Planning


Operational 2001–2015
2016
2018
2020
2022
Mars Express (ESA)
Mars Odyssey
Mars Reconnaissance Orbiter
MAVEN
Mars Orbiter Mission (ISRO)
Trace Gas Orbiter (ESA)
Future Planning
Opportunity Rover
Curiosity Rover
InSight
ExoMars Rover (ESA)
Science Rover
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers
Credit: NASA

MRO Spacecraft

***Telecom*:**
- X, Ka-Band & UHF
- 100 W X-Band TWTAs
- 3-m diameter High Gain Antenna

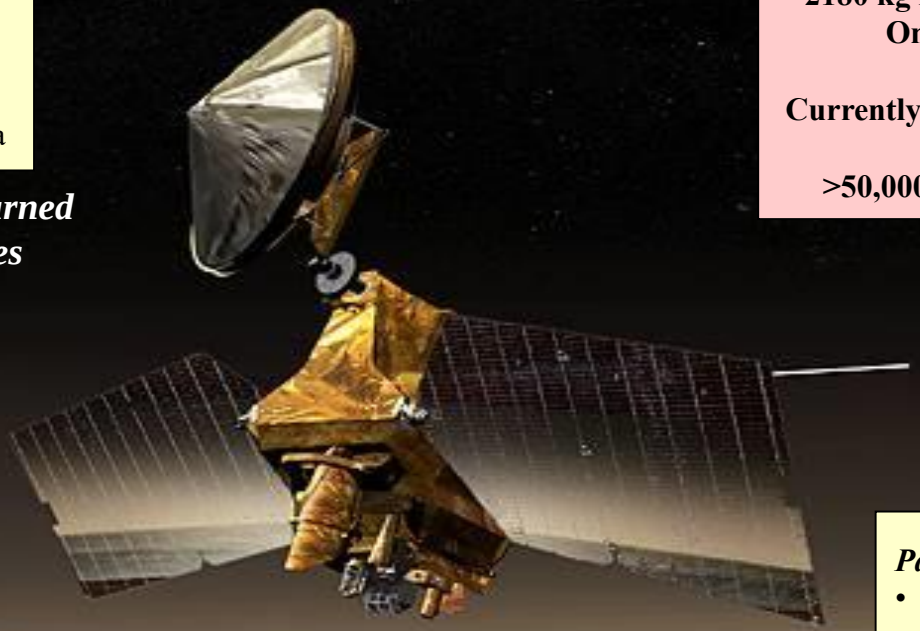
- ***>300 Tb of Science Data Returned***
- ***Retransmit capability increases reliability***

***Power*:**
- Dual 50 A-Hr NH_2 Batteries
- 20 m^2 of GaAs 3J Solar Cells

Supports Continuous Payload Operations

***Propulsion*:**
- Single-Tank Mono Prop Design
- 20 Yrs Consumables

Fuel Not a Limit



2180 kg Launch Mass (Atlas V)
On August 12, 2005

Currently in 4th Extended Mission

>50,000 orbits around Mars!

10 m radar antenna

***Payload*:**
- **6 Science Payloads**
- **2 Eng Payload**
- **Electra Eng SS**
- **Simultaneous Operations**
- **Nested Targeting**

All science payloads still operating after 10+ years

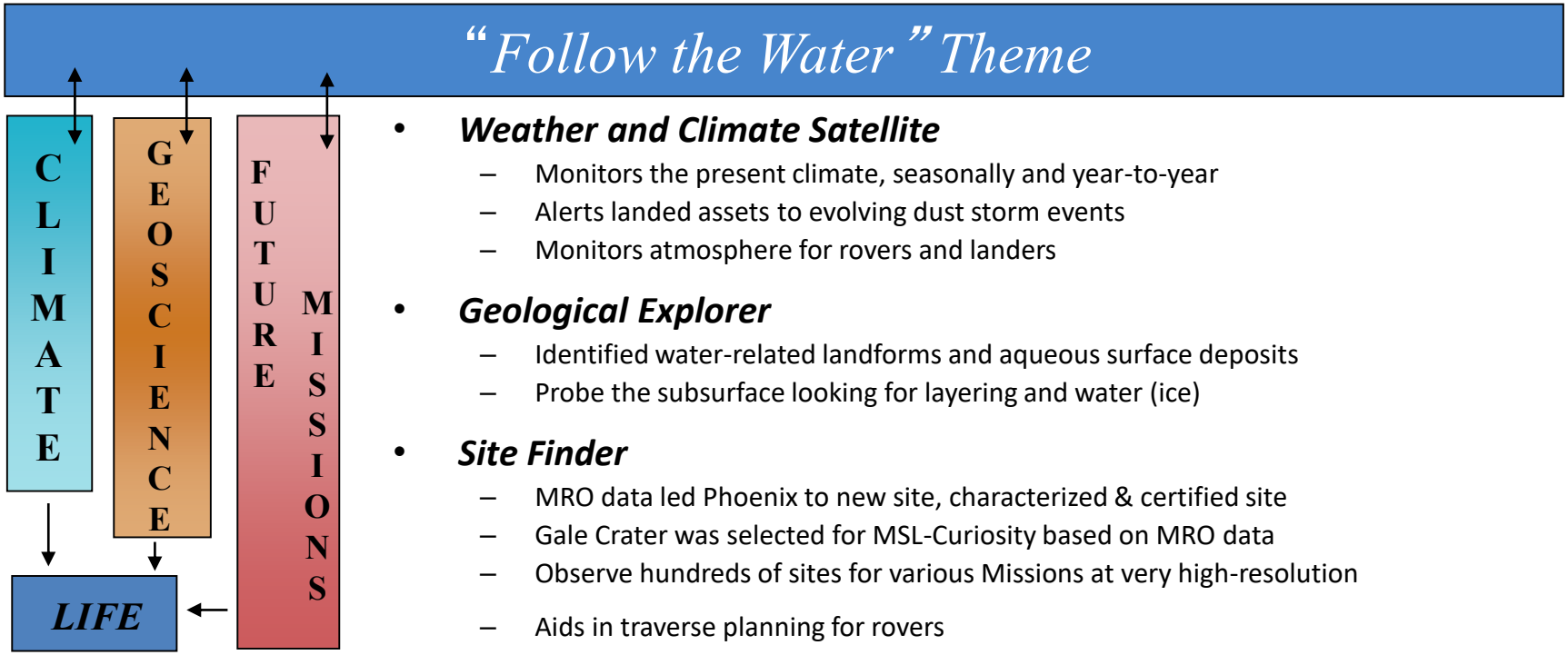
***Targeting*:**
- Ephemeris-Based Targeting
- Time-Tagged Sequence Fully Supported

- ***Precise targeting of almost any small target on Mars within a 2 week planning cycle***
- ***Can roll off-nadir***

***Command/Data Handling*:**
- **RAD750 FPC**
- **160 Gbit SSR**
- **100 Mbps Science I/F**

Slide adapted from Rich Zurek

MRO's Many Roles

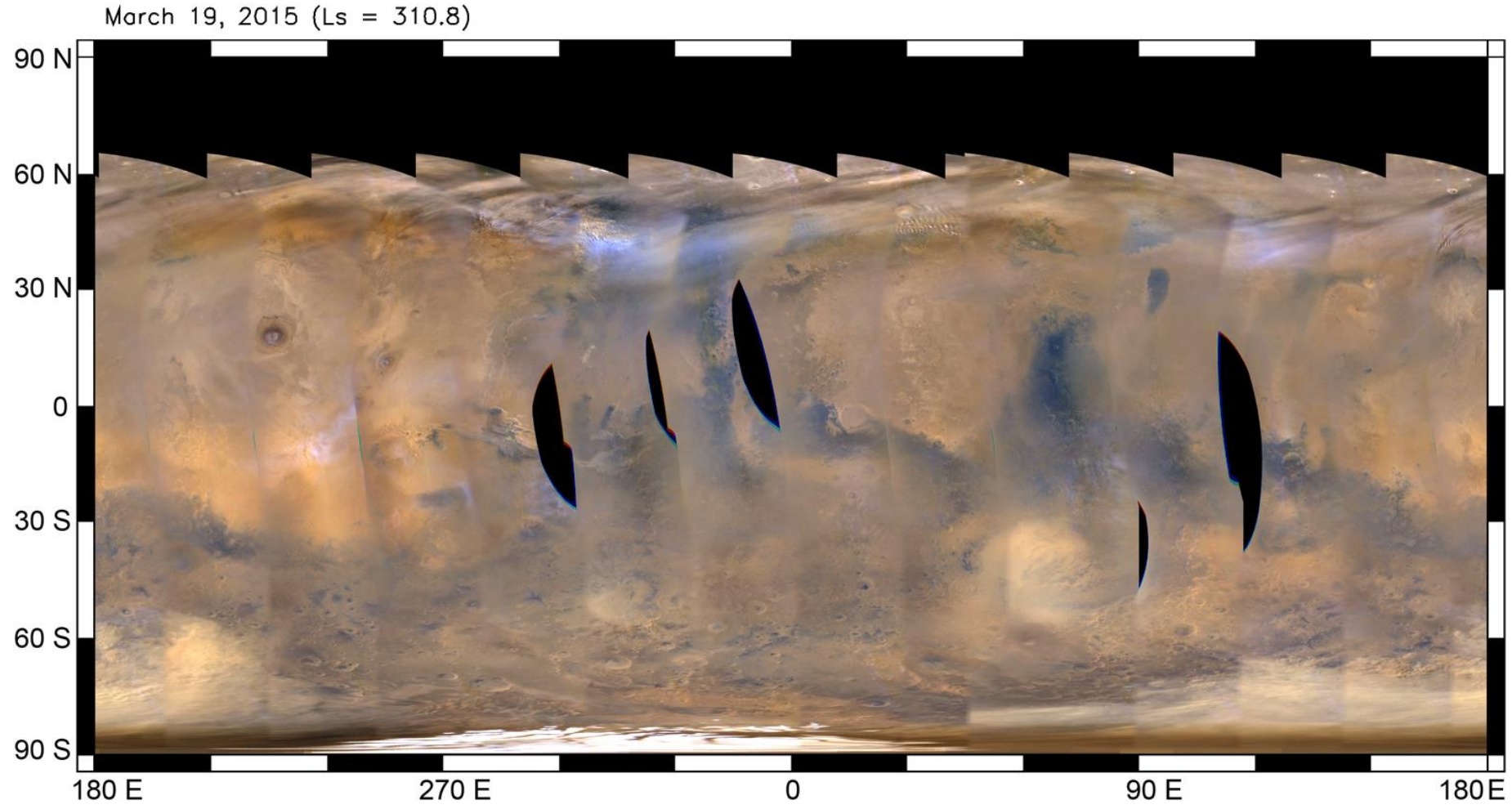


- ***Weather and Climate Satellite***
  - Monitors the present climate, seasonally and year-to-year
  - Alerts landed assets to evolving dust storm events
  - Monitors atmosphere for rovers and landers
- ***Geological Explorer***
  - Identified water-related landforms and aqueous surface deposits
  - Probe the subsurface looking for layering and water (ice)
- ***Site Finder***
  - MRO data led Phoenix to new site, characterized & certified site
  - Gale Crater was selected for MSL-Curiosity based on MRO data
  - Observe hundreds of sites for various Missions at very high-resolution
  - Aids in traverse planning for rovers
- ***Technology Pathfinder***
  - Demonstrated optical navigation and use of new telecom frequencies (Ka-band) for future missions
- ***Communications Satellite***
  - Provided critical event coverage (EDL) and relay for Phoenix and MSL
  - Provides relay for Mars Science Laboratory (~450 Mb/sol) and Mars Exploration Rover (MER)-B

Slide adapted from Rich Zurek and Dan Johnston

MRO's Many Roles

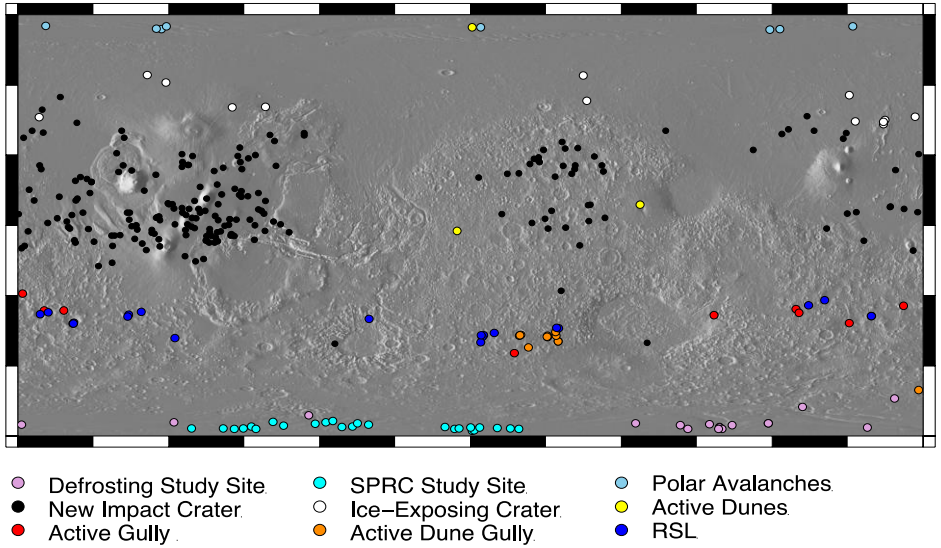
MRO as a Weather and Climate Satellite

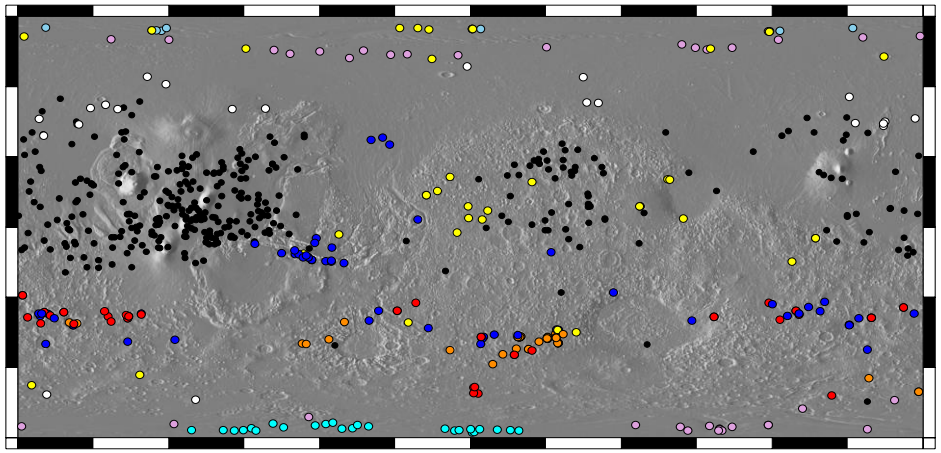


Slide adapted from Rich Zurek and Dan Johnston

MRO's Many Roles

MRO as a Geological Explorer

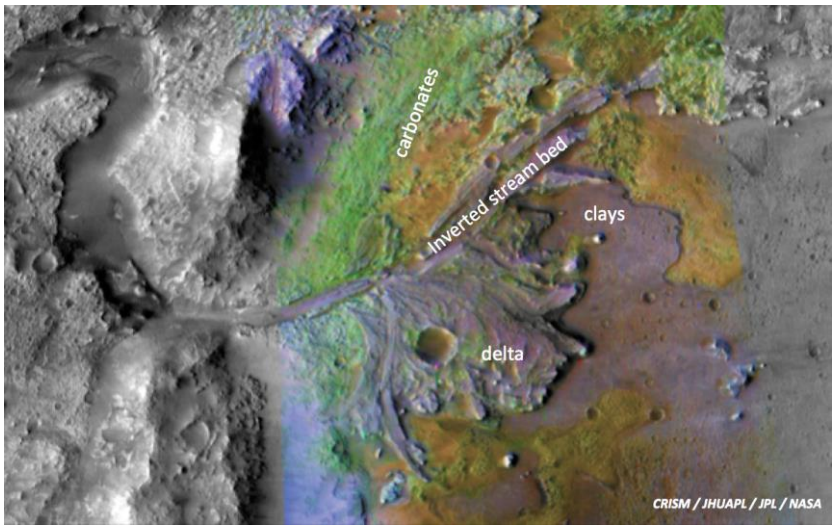




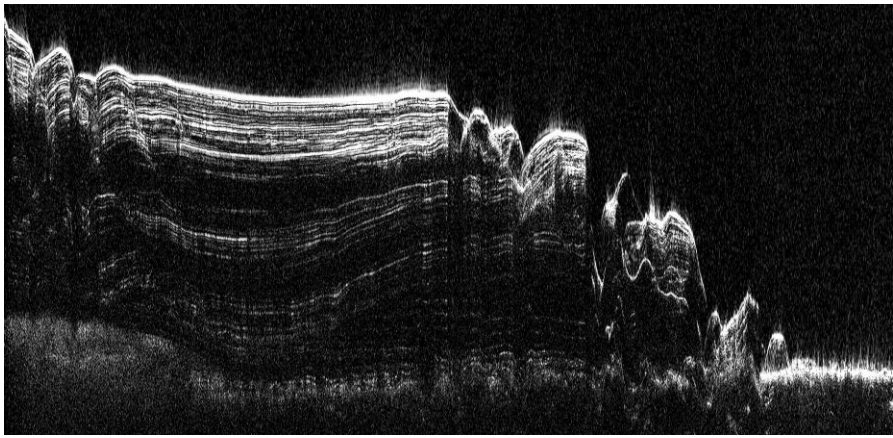
McEwen and Byrne

Early 2012 (top) vs. Feb 2014 (bottom)

Message: accelerating progress over time (HiRISE)



Jezero Crater: Morphology and Mineralogy Indicate Ancient Wet Past (CRISM)

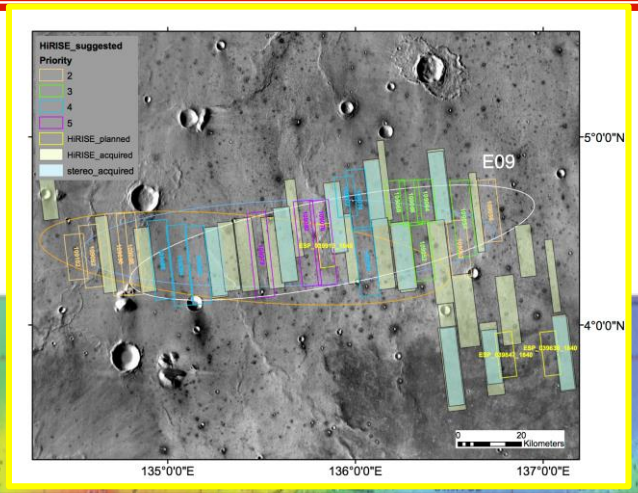


Layers of ice and dust cause radar reflections (SHARAD)

- Each layer records a different depositional environment
- Each layer represents a change in climate

MRO's Many Roles

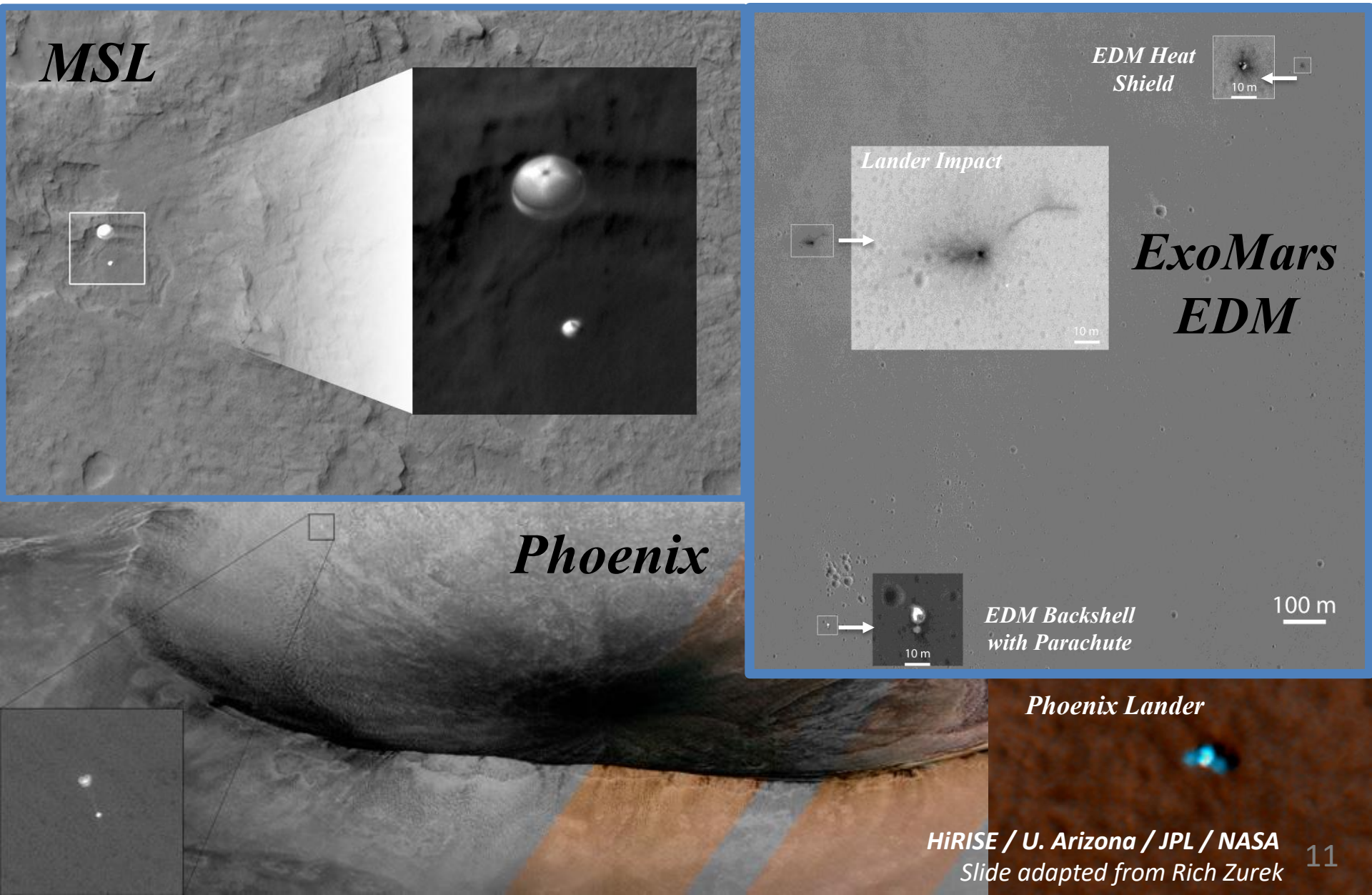
MRO as a Site Finder



As of February 25, 2016

MRO's Many Roles

MRO as a Communications Satellite

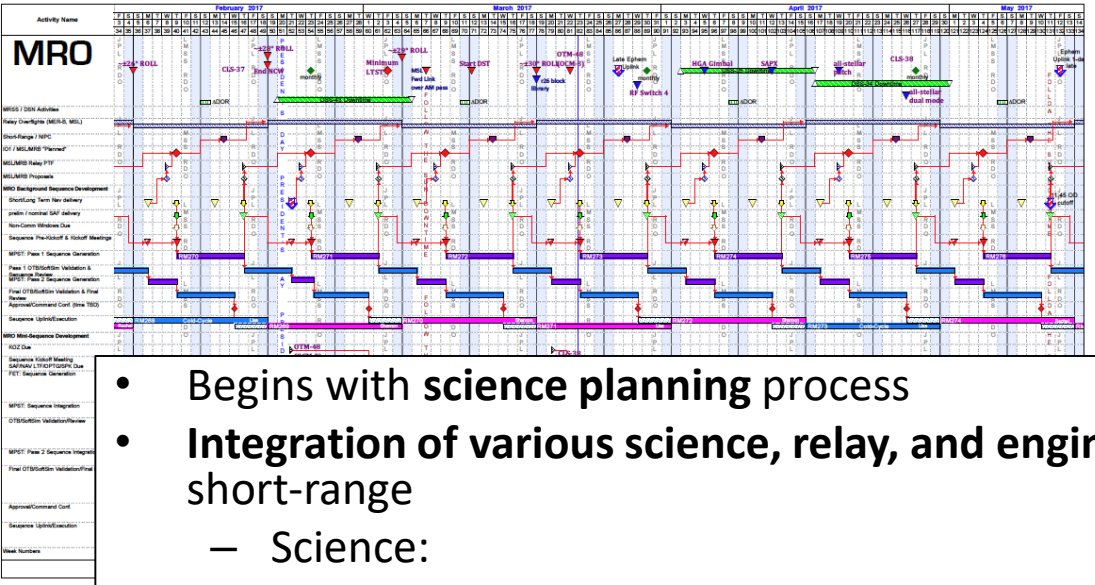


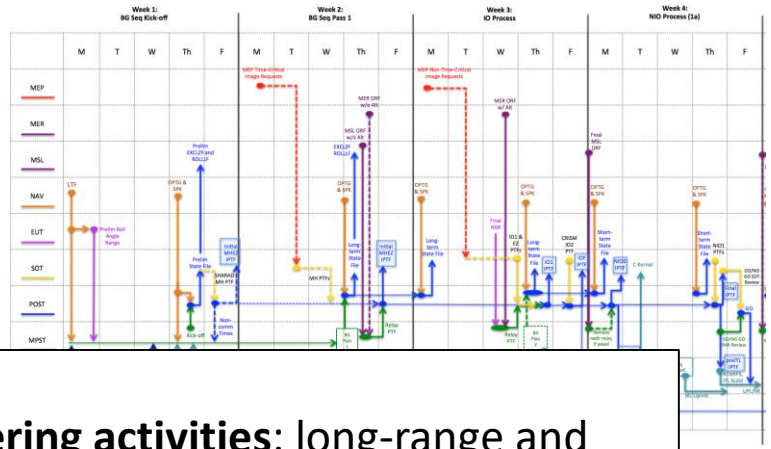
HiRISE / U. Arizona / JPL / NASA

Slide adapted from Rich Zurek

Science Planning

Data Request → Acquisition



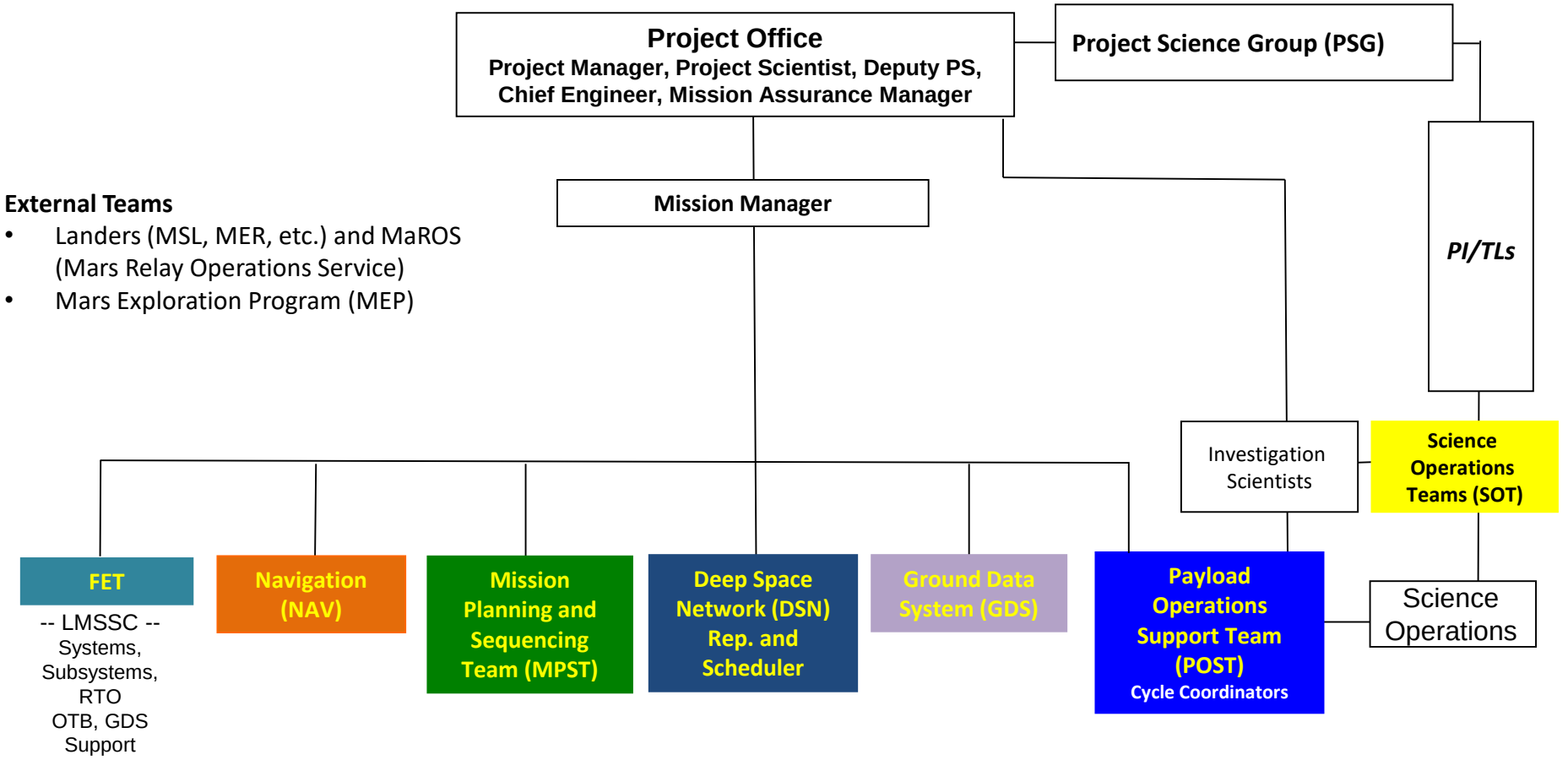


- Begins with **science planning** process
- **Integration of various science, relay, and engineering activities**: long-range and short-range
  - Science:
    - Targeted or nadir observations of surface
    - Special one-time observations or campaigns
    - Relay passes with landed assets
  - Engineering:
    - Desats
    - HGA (Comm) management for playback of data to Earth
    - Solar array movement
    - Gimbal motion exercises
  - Science Planning lies at the interface between science and engineering

MRO Science Planning

MRO Operations Teams

Science Planning is one team out of many on MRO

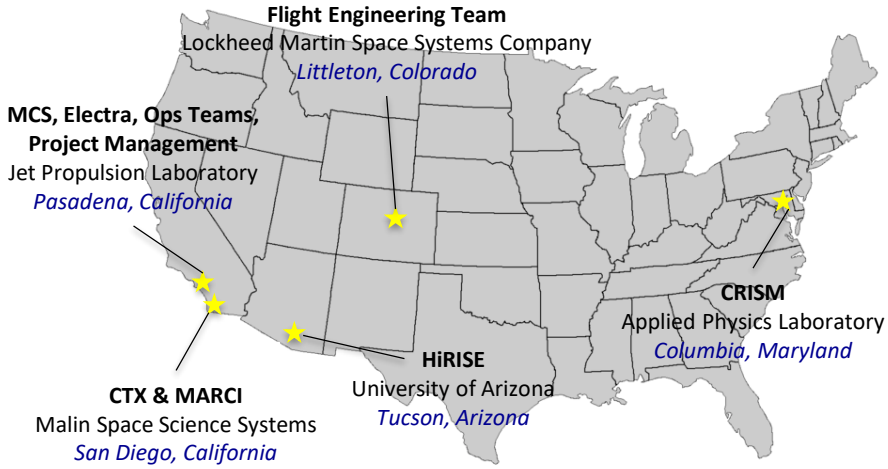


Slide adapted from Dan Johnston

MRO Science Planning

Challenges

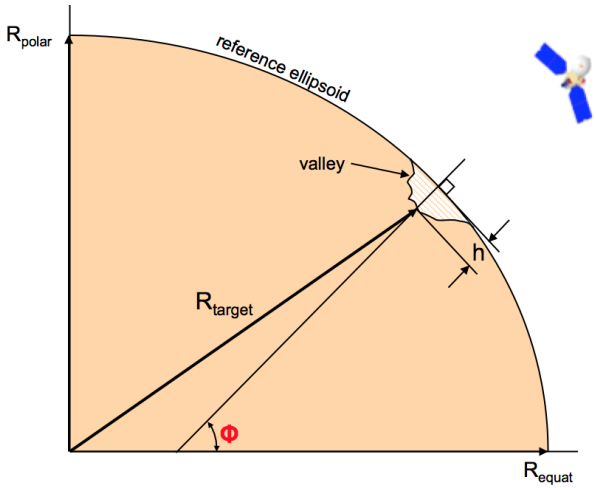
- Distributed operations teams
- Terminology of engineer vs. scientist
- Incompatible science motives
- Instrument constraints
- S/C constraints
- New requirements



MRO Science Planning

End Goal: Integrated Target List (ITL)

- List of targets for various instrument observations organized by S/C kickoff time
  - On-board software computes positions of the target
- Each line represents a target point on Mars
  - An estimated time of overflight (specified in SCLK seconds)
  - Location on planet
    - Areodetic latitude *
    - East longitude *
    - Height correction for terrain *
  - Instrument parameters:
    - Setup time
    - Imaging time
    - File names, sequence names



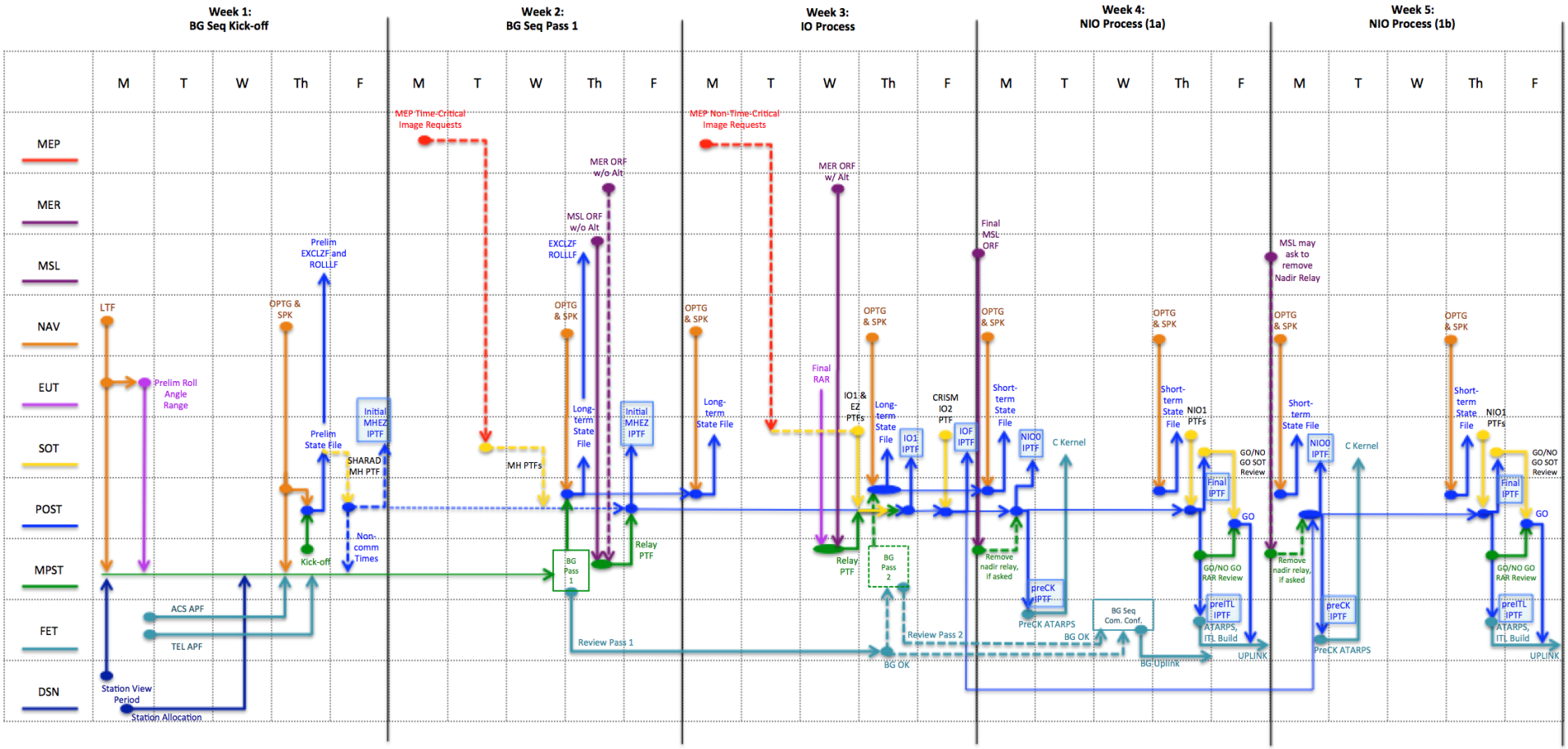
- ITL targets will be rejected by the onboard software if they fail any of several constraint checks

* As defined by a reference ellipsoid common to flight software and ground tools

Slide adapted from Mark Johnson

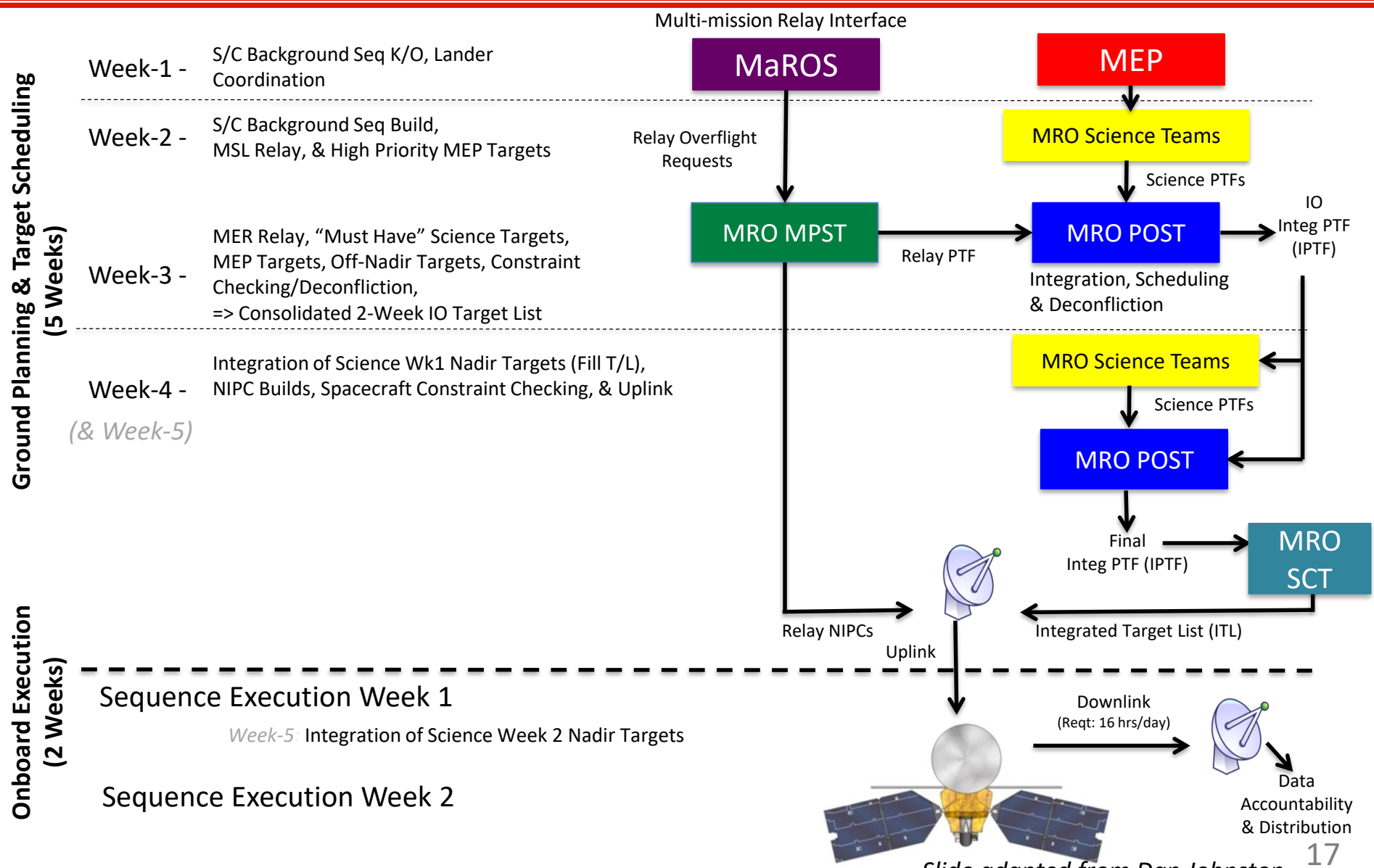
MRO Science Planning

Science Planning Process Schedule



MRO Science Planning

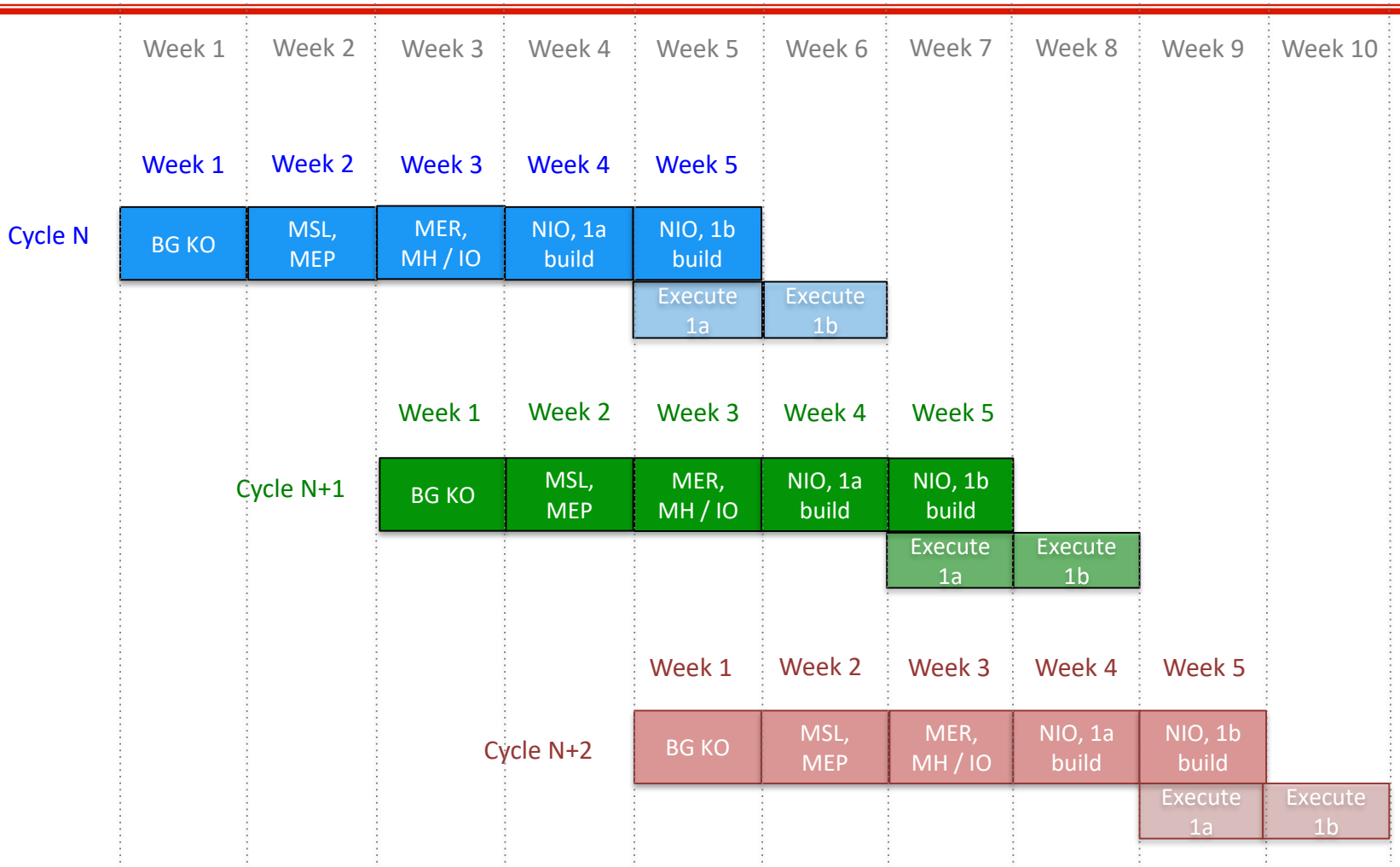
Science Planning Process Overview



Slide adapted from Dan Johnston

MRO Planning Schedule

Science Planning Process Cycle Overlaps

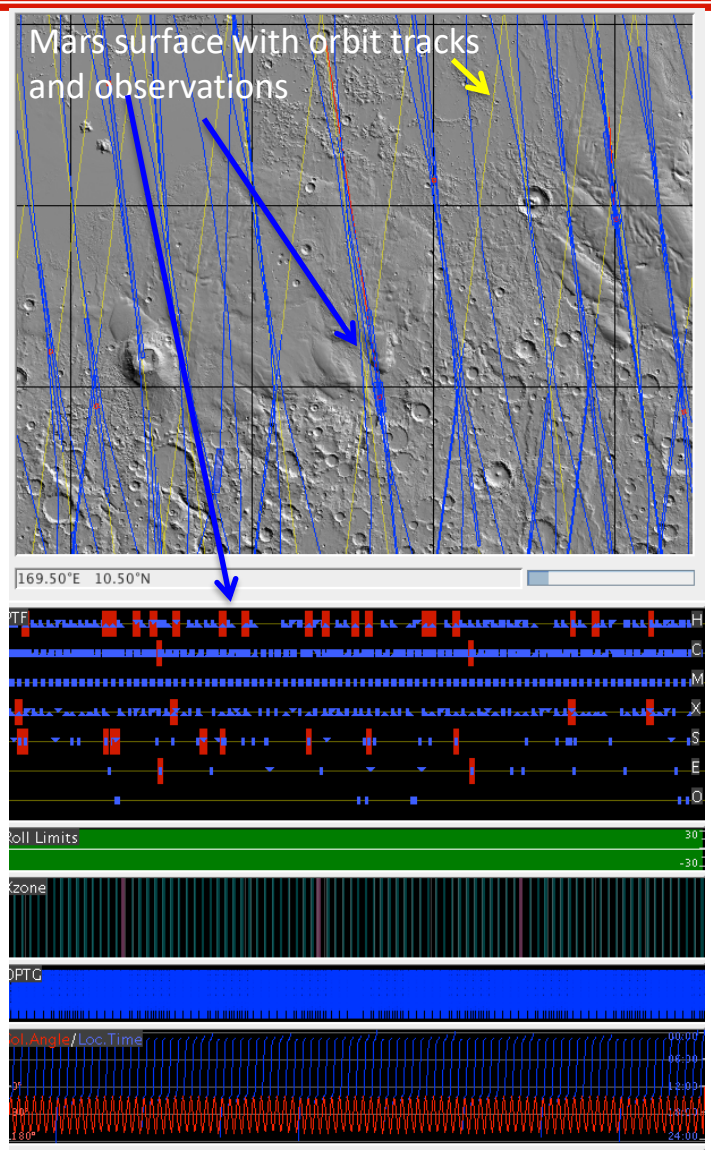


Reaction to any observations from N will not get into plan until N+2 at earliest

MRO Science Planning

Planning Software

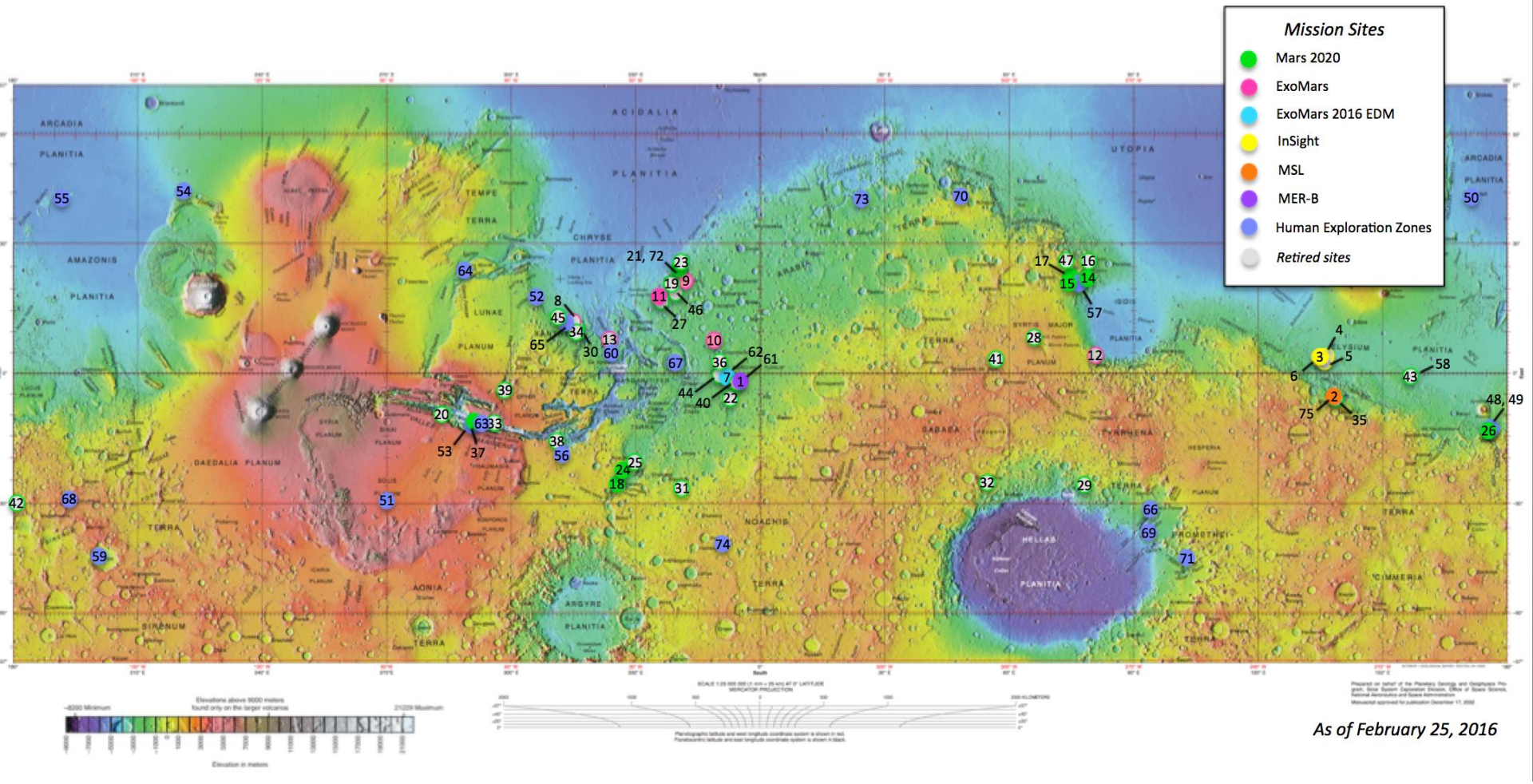
- Use various scheduling software to aid in the science planning process
  - Visual representation of timeline via the Mars Targeting Tool, layer on top of JMARS (*Java Mission-planning and Analysis for Remote Sensing)*
  - Instrument teams tools and scripts
  - Several in-house scripts schedule observations
    - Based on priority of each team's own records
    - Schedule highest priority MHs first, followed by interactive stereo 2 observations by team, other interactive observations in round robin fashion, ride-alongs, nadir observations
  - Final check on target list performed by Systems at JPL or LMSCC (Denver), LMSCC performs check on S/C and gimbal motion



JMARS MTT

Landing Site Selection

Example of Science Planning on MRO



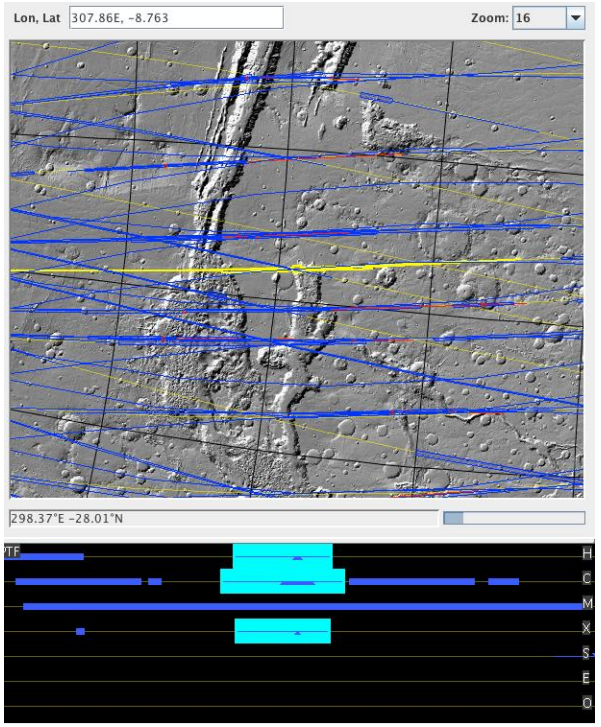
- MRO has supported or supports: PHX, MER, MSL, InSight, ExoMars, Mars 2020, Human Exploration Zones
- Over 800 mission targets on current campaign list (and 85% have been acquired)!

Landing Site Selection

Example of Science Planning on MRO

Before the MRO Science Planners integrate the records, initial requests are fed into the process through the Instrument Teams

- Team/Individual selects a “driving” instrument
  - Determined based on the coverage requested
  - Center of target based on selected “driver”
- Other instruments can “ride-along”
  - Co-centered coverage by several instruments
  - CTX will automatically support a HiRISE-driven target
- Certain observations can only be acquired during specific time periods
  - Stereo completion requests
  - CRISM IR requests

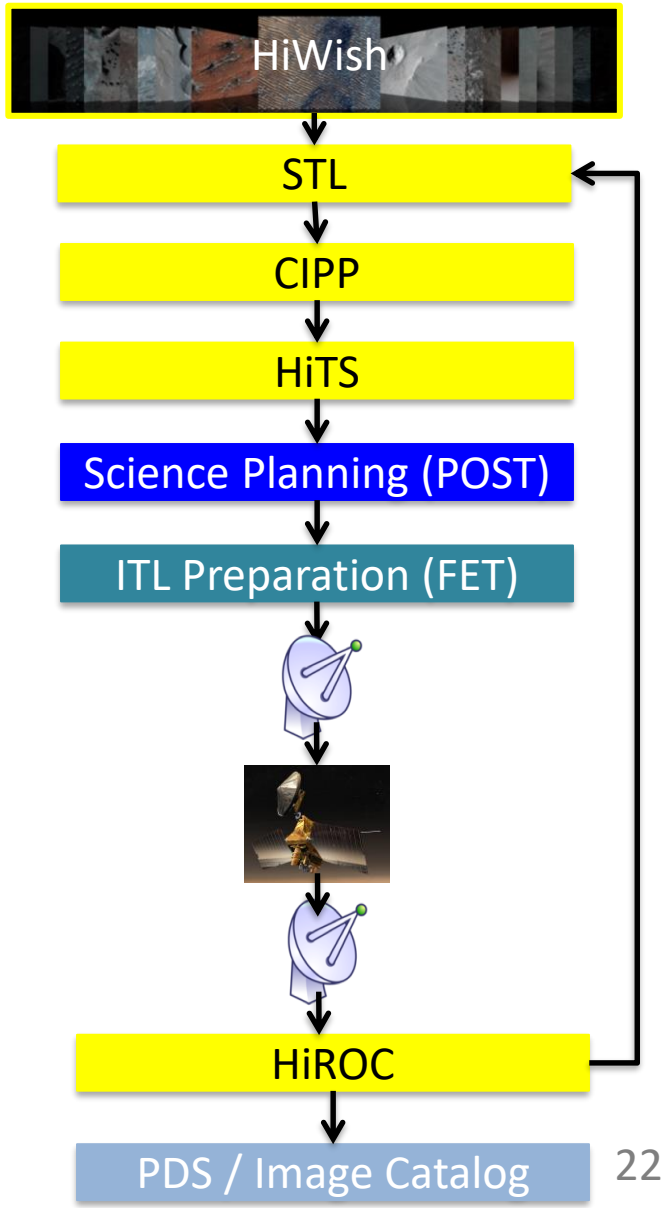


- HiRISE targets submitted via HiWish
  - Open to public and scientists alike
  - http://www.uahirise.org/hiwish/
  - Can browse suggestions or acquired images

Landing Site Selection

Example of Science Planning on MRO via HiWish

- Once target is submitted via HiWish, HiRISE Science Theme Leads (STLs) look at requests and prioritize based on the science rationale
- Science team members (CIPPs) plan the images
- Targeting Specialists (HiTS) examine details and plan observations
- A suggested is “retired” if it has been planned into the ITL via the MRO Science Planning process
- HiRISE observes the target and MRO transmits the raw image data to Earth
- Automated processes convert the data to image products
- HiRISE staff looks at the data to determine if the product is usable
  - If not, the original suggestion “unretired” and fed back into science planning loop
  - If usable, images are released to public with PDS release, sometimes sooner in the online image catalog

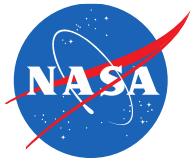


MRO Science Planning

Summary

- Science Planning is the integration of various science, relay, and engineering activities
- Relay and science are all planned in the same science planning process on MRO
- Various challenges in science planning based on ground or S/C configuration; many met through constraints and allocations
- Takes several weeks to plan request and acquire
- Takes weeks – years from original request in system based on type and priority of data requested!


Questions?
Thank you!



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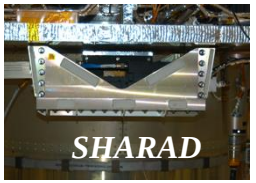
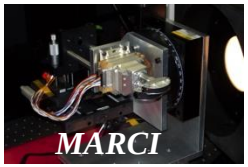
Backup

MRO Science Investigations

Instrument	Type	PI/TL, Institution	Attributes
CRISM	Hyper-Spectral Imaging VIS-NIR Spectrometers	Scott Murchie, PI APL / Johns Hopkins University	Targeted Observing @ 18 m/pixel Regional Survey @ 100-200 m/pixel Very High Data Rate 85% of Mars surveyed in 544 channels
HiRISE	Very High Resolution Imaging	Alfred McEwen, PI University of Arizona	Targeted Imaging @ 30 cm/pixel Swath: 5.4 km w. 1.2 km 3-color strip Very High Data Rate / 2.7% of Mars
SHARAD	Shallow Subsurface RADAR (Provided by ASI)	Roberto Seu, TL/PI University of Rome Roger Phillips, rDTL Nathaniel Putzig, aDTL	Regional Radar Profiling of Subsurface Profiles to 0.5 km in regolith / 1.5 km in ice @ ~10 m vertical resolution High Data Rate
CTX	High-Resolution Context Imager	Michael Malin, TL Malin Space Science Systems	Targeted & Regional Survey 6 m/pixel, panchromatic in 30 km swath High Data Rate / 98% of Mars
MARCI	Mars Color Imager	Michael Malin, PI Malin Space Science Systems	Daily Global Mapping ~1 km/pixel in 7 color bands Moderate Data Rate / > 5.4 Mars yrs.
MCS	Mars Climate Sounder	Daniel McCleese, PI JPL / Caltech	Daily Global Sounding (T, p, aerosols) ~5 to 80 km Low-Data Rate / > 5.4 Mars yrs.
ACCEL	Facility Science Team Investigation	Gerald Keating*, TL GWU / LaRC	Profiled upper atmosphere using S/C Accelerometers during Aerobraking. (complete)
Gravity Science	Facility Science Team Investigation	Maria Zuber, TL MIT / GSFC	Data from DSN tracking using Spacecraft X Band Telecom





Slide from Rich Zurek